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BULLETIN No. 56 - 2 C

THE EFFECT OF MANURES

ON THE

SHOT-HOLE BORER OF TEA

(*Zythgorus fornicatus*, Ebel.).

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DEPARTMENT OF AGRICULTURE, CEYLON.

BULLETIN No. 56.

THE EFFECT OF MANURES ON THE
SHOT-HOLE BORER OF TEA.



HE opinion that high cultivation exercises a controlling influence upon the activities of Shot-hole Borer (*Xyleborus fornicatus*) on tea estates where this pest occurs is almost unanimously held by planters. There is, however, considerable divergence of opinion as to what particular manures exercise this control, and as to the manner in which it is effected. The following extracts from communications received from planters indicate some of the opinions held as to the effect of manures on Shot-hole Borer:—

A.—“Owing to continuous application of manure I consider it (Shot-hole Borer) has decreased twenty per cent.”

B.—“The borer was on the decrease, due to a liberal manuring system, but such decrease has been temporarily suspended with temporary cessation of manuring.”

C.—“Nitrate of soda was put out in an 18-acre field six months after pruning . . . I have also noticed in this field that borer was almost absent, which shows the good effects this manure had in producing sap, and if sap is running well, borer will not attack the branches.”

D.—“The results of application of ephos phosphate and muriate of potash, together with a full manure mixture, gave excellent results as regards yield, and the reduction of bore has been most marked.”

It will be noted that a reduction in Shot-hole Borer attack is attributed by A and B to the effect of a general manure mixture, by C to nitrate of soda alone, and by D to the effect of a mixture with an excess of potash and phosphoric acid. Opinions that decrease of Shot-hole Borer attack is due to the application of manures, of mixtures without potash, of green manures, &c., have also been expressed, but the above will suffice to show that, though there is a certain unanimity as to the effect of manures in general, there is considerable divergence of opinion as to what manurial elements are most effective in bringing about a reduction of borer attack.

That some elements used as manure have an inhibitory effect on certain insects has been shown by Andrews' recent work* in India with *Helopeltis*. As a result of his experiments, he concluded that the presence of available potash in sufficient quantity had the effect of rendering tea bushes immune to attacks by this pest. His investigations have been followed with much interest in Ceylon, and it has been suggested that potash may have a similar effect on Shot-hole Borer. The method of feeding of *Helopeltis* and of Shot-hole Borer are entirely different. The former subsists by piercing the leaves and sucking the juice therefrom, while the latter does not depend directly, at any stage of its existence, on any part of the tea bush for its nourishment. The Shot-hole Borer, in both adult and larval stages, feeds solely upon an “*Ambrosia*” fungus, which is introduced into the gallery by the parent beetle, and which is grown upon the walls of the gallery. Though the presence of certain salts in the sap may render a plant distasteful to sucking insects like *Helopeltis*, it is unlikely that it would have a similar effect on Shot-hole Borer, which feeds only on the fungus. The “*Ambrosia*” fungus, however, draws upon the sap and reserves of food material in the tea wood for its nourishment. If the sap, owing to the presence of some element in it, became unsuitable for the fungus, the beetles would be deprived of their normal food supply, and be

* Andrews, E. A. : “A preliminary note on the present state of the Mosquito-blight Inquiry.” *Quart. Journ. Scientific Dept. Indian Tea Assoc.*, 1919, Part 4, pp. 119-129.

compelled to leave the bush. Obviously, this element, though detrimental to the fungus, must not be harmful to the tea. Possibly some such element exists amongst the various manurial substances commonly used, if manurial treatment is followed by a diminution of Shot-hole Borer attack.

Where diminution of attack follows manurial treatment, the control of the insect may be exercised in other ways than through the "Ambrosia" fungus. It is well known that certain manures, mainly potassic, cause the production of hard wood. It may be possible, though it appears somewhat improbable, that by the use of such manures the wood may become too hard for the beetle to enter. It has also been suggested (opinion C) that, "where sap is running well," borer will not attack the branches, and that nitrate of soda induces such a flow of sap.

An effective means of controlling Shot-hole Borer by cultural and manurial methods would readily commend itself to the planter. It appeared desirable, therefore, to determine the relative value, in reducing borer attack, of the various manures commonly used on estates, and the manner in which they exercise their control.

The use of manures, primarily, is to improve the general health and growth of the bushes. An increase in vegetative vigour will enable the bushes better to withstand attack by insect pests, and to repair more readily any damage caused by such. Shot-hole Borer, in constructing its galleries in the branches of the bush, so weakens those branches that they are easily broken. The destruction of branches in this manner is the primary damage caused by this insect. It has frequently been noted that in well and regularly manured fields the entrances to borer galleries are completely healed over and sealed by a plug of wood. The healing of the galleries in this fashion materially strengthens the branches, which, consequently, are less liable to be broken. Where bushes are very vigorous and the bored branches heal readily, any damage done by borer is not so noticeable, there being fewer broken branches. The absence of broken branches, together with the improved appearance of the bushes due to manuring, may lead to the opinion that Shot-hole Borer attack is on the decrease, whereas really the insects may be just as prevalent, though the effects of their attack are not so noticeable. The apparent decrease of borer subsequent to manuring may thus be due, not so much to an actual

decrease in the number of beetles and their galleries, as to the effects of the attack being obscured by the increased vigour of the bush.

The general appearance of the bush, therefore, cannot be used as a criterion in determining experimentally whether a decrease of Shot-hole Borer follows the application of manures. Also there must be similar unmanured plots alongside the treated ones in order to determine whether any diminution of attack observed is due to climatic or other conditions, and not directly to the effect of manures.

The following experiments were regarded as being of a preliminary character. Their object was to determine, in the shortest possible time, whether a reduction of borer attack follows treatment with certain manures, and, if possible, to ascertain how this reduction is brought about. From the results of these preliminary experiments it would be seen whether further experiments are desirable, and with the experience gained, it would then be possible to devise others by which the intensity of borer attack could be measured more accurately.

Arrangement of Plots.

Through the courtesy of Colonel W. G. B. Dickson* the use of three fields on Sarnia estate, Badulla, were placed at the disposal of the Department of Agriculture for the purpose of these experiments. These fields are typical of up-country estates, and had been regularly cultivated and manured. Tea which had never been manured with artificials would undoubtedly have been better for the purposes of the experiment, but as none was available, Colonel Dickson's offer was accepted.

In each field sixteen plots, each consisting of 378 bushes, i.e., 18 rows each of 21 bushes, were laid out. Each plot was separated from the adjoining plots by guard strips four bushes wide, which were left untreated. In this way the risk of the manure applied to one plot affecting the bushes on the boundaries of the adjoining plots was reduced to a minimum. Figure 1 shows the arrangement of plots in each field.

* The thanks of the Department of Agriculture are due to the Scottish Trust and Loan Company of Ceylon for providing land and labour for these experiments free of charge, and also to Mr. S. E. Grant-Cook, Superintendent of Sarnia Estate, for much assistance rendered during the course of the experiments.

Plot 13. Control.	Plot 14. Nitrate of Soda. 200 lb. per Acre.	Plot 15. Muriato of Pot ash 200 lb. per Acre.	Plot 16. Sulphate of Ammonia. 200 lb. per Acre.
Plot 9. Lime. 5 tons per Acre.	Plot 10. Control.	Plot 11. Dadap Loppings. 5 tons per Acre.	Plot 12. Basic Slag. 300 lb. per Acre.
Plot 5. Boga Loppings. 5 tons per Acre.	Plot 6. Nitrate of Potash. 200 lb. per Acre.	Plot 7. Control.	Plot 8. Nitrolim. 200 lb. per Acre.
Plot 1. Nitrate of Soda and Ephos Phosphate. 200 lb. per Acre.	Plot 2. Cattle Manure. 7 tons per Acre.	Plot 3. Ephos Phosphate. 200 lb. per Acre.	Plot 4. Control.

FIG. 1.—PLAN OF PLOTS.

The areas selected were as even as could be obtained, both as regards the size of bushes and the intensity of Shot-hole Borer attack. More attention was paid in selecting the experimental areas towards obtaining uniformity as regards borer attack than as regards size of bushes, as the former character was considered to be the more important. The selection was made from the general appearance of the bushes, and not from actual counts of the number of galleries present.

The three fields for the purposes of experiment were known as A, B, and C, and the plots in each field were numbered 1-16. All plots bearing the same number were similarly treated. The bushes in the different fields were of different ages from the time of pruning. All plots in field A were entering their third year, in field B their second year, and in field C they were pruned shortly before the commencement of the experiments. In each field four plots were left unmanured as controls.

Manures used.

The fertilizers selected* for trial were those possessing high percentages of nitrogen, potash, and phosphoric acid. The nitrogenous manures selected were nitrate of soda; sulphate of ammonia, and nitrolim; the potassic, muriate of potash; and the phosphatic, basic slag and ephos phosphate. A combination of nitrogen and potash was provided by nitrate of potash; of nitrogen and phosphoric acid by a mixture of nitrate of soda and ephos phosphate. No complete artificial mixtures were used, as another series of experiments was started to determine the value, as a control for the Shot-hole Borer, of such mixtures applied at varying rates. The latter experiments are still in progress, and so will not be dealt with in the present paper. Organic manures, represented by cattle manure, dadap, and boga medeloa (*Tephrosia candida*) loppings, were, however, included in the present series, as was also lime. A full list of the manures, together with their chemical analyses, the rates at which they were applied, and other details, are given in Table 1. The chemical analyses of the artificial manures were provided by the suppliers of the manures, and those of cattle manure, dadap, and boga loppings by the Government Agricultural Chemist.

* The Department of Agriculture is indebted to the Colombo Commercial Co., Ltd., for the free gift of all the artificial manures used in these experiments, and to the proprietors of Sarnia Estate, Badulla, for supplying cattle and green manures without charge.

Table 1.

Plot No.	Manure.	Analysis.			Plant Food in lb. per Acre.		
		Nitrogen per Cent.	Phosphoric Acid per Cent.	Potash per Cent.	Rate applied per Acre.	Nitrogen.	Phosphoric Acid.
14	Nitrate of soda ..	15·00	—	—	200	30·00	—
16	Sulphate of ammonia ..	20·00	—	—	200	40·00	—
8	Nitrolim ..	18·00	—	—	200	36·00	—
15	Muriate of potash ..	—	—	45·00	200	—	90·00
3	Ephos phosphate ..	—	30·00	—	200	—	—
12	Basic slag ..	—	17·00	—	300	—	—
6	Nitrate of potash ..	10·00	—	35·00	200	20·00	70·00
1	Nitrate of soda and ephos phosphate ..	15·00	30·00	—	200	30·00	60·00
11	Dadap loppings ..	·84	·08	·14	·5	·94·08	8·96
5	Boga medelona lop- pings ..	1·00	·13	·56	5	112·00	14·56
2	Cattle manure ..	·69	·32	·29	7	108·19	50·18
9	Lime ..	—	—	—	5	—	25·47

In order to allow all bushes in the treated plots to obtain equal benefits from the applications, the manures were applied in every row, instead of alternate rows as is the usual practice on estates. The forking was done to a depth of six inches. The dadap and boga loppings were cut into small pieces, spread evenly, and forked in. Lime was applied at the very high rate of 5 tons per acre, as it was considered that nothing less could give definite results.

Dates of Manuring and Examinations of the Fields.

Field A.—In this field the artificial manures were applied on November 17, 1920, and the organic manures and lime on the two succeeding days. The field had been last pruned in October, 1918. The plots, therefore, at the time of treatment, had just entered their third year from pruning. The final examinations of the plots were made between July 21 and 26, 1921, eight months after treatment, and shortly before they were again pruned.

Field B.—These plots received their manurial dressings on November 15 and 16, and the lime plot was treated on November 19. At the time of treatment the bushes had run one year from their last pruning, which had occurred in September, 1919. The final examinations of the plots were made from July 11 to 19, 1921.

Field C.—This field was pruned in August, 1920, and the prunings mulched on the surface. Thus, the control plots as well as all treated plots received this mulch of prunings. The manures should have been applied immediately after pruning, but owing to a drought in the district the ground was so hard that manuring was postponed until the weather conditions became more favourable. On November 12, 13, and 20 the artificial fertilizers, organic manures, and lime were applied to their respective plots. The plots were due for their final examination in October, 1921, but it was found at that time that the attack was so slight, even in the control plots, as to be almost negligible. It was decided, therefore, to postpone the final examination for some months. As it was considered advisable to renew the treatment of the plots, this was done on December 8, 9, and 12, 1921. The dressing of lime on plot No. 9 was, however, reduced to the rate of one ton per acre, as it appeared inadvisable to repeat the very heavy dressing given in the original treatment. The quantities of each manure in other plots for this second dressing were the same as for the original one, and the methods of application were also the same. The final examination was ultimately made between February 13 and 16, 1922, *i.e.*, sixteen months after the first treatment, when the attack, though still small, was considered to be sufficient for a comparison to be made between the various plots as to the extent to which they were attacked by borer.

Measurement of Attack.

Before the plots could be compared, it was essential to devise a method of measuring the intensity of Shot-hole Borer attack with some degree of accuracy. It must be realized that the extent to which any tea bush is attacked depends, not only upon the number of insects present in the field and capable of attacking the bush, but also upon the size of the bush itself. It is well known that the borer will only enter branches which have a sufficient diameter to hold a gallery, and that it will not enter whippy twigs. It follows therefore that, other things being equal, a large well-developed

bush runs a greater risk of attack than does a smaller bush, as the former contains more wood suitable for borers to enter. Tea bushes normally vary considerably in size even in apparently uniform fields ; and in these experiments, as some plots are manured, whereas others are not, it is to be expected that the bushes of certain manured plots will attain greater growth than those of unmanured plots. Consequently, unless the manure has in some way a repellent action on the borers, the plots with the larger bushes will contain the more borers, because in those plots there is more wood suitable for attack. It becomes obvious, therefore, that in measuring the intensity of attack, the size of the bush must be taken into account. As regards the size of the bush, the essential character to be considered is the area of wood surface suitable for attack, but it was found impracticable to measure this directly. It was found, however, that the number of branches arising from the old frame, of sufficient diameter to allow the entry of the insect, gave approximate measurement of the size of the bush. By dividing the total number of galleries found in the bush by the total number of branches, the number of galleries per branch was obtained, and this was considered to be a satisfactory unit for the measurement of attack.

It will be readily seen that a bush having 50 branches and 50 galleries is attacked to the same extent as a larger bush of 70 branches with 70 galleries, as each bush has an average of one gallery per branch. Similarly, a bush with only 30 branches and 15 galleries is more severely attacked than a larger bush with 60 branches and 24 galleries, as the former has 5 galleries per branch, whereas the latter has only 4 galleries per branch.

Method of Examination in the Field.

Since, in order to measure the intensity of attack, the number of branches as well as the number of galleries in each bush had to be counted, the examination of every bush in each plot became an impossible task. It was decided, therefore, to examine 50 bushes only in each plot, and that the results obtained from those bushes should be taken to represent the attack of the plot. It was found, however, that where bushes were severely attacked, a maximum of 3 bushes only could be completely examined, even with the aid of an assistant and two trained coolies, in the course of an hour. As, according to this programme, 2,400 bushes had

to be examined in the three series of plots, it became necessary to reduce still further the number of bushes in each plot to be examined. Ultimately it was decided that 25 was the smallest number that could be used with accuracy.

As 25 representative bushes had to be selected from each plot containing about 400 bushes, some suitable method of sampling had to be used. It was essential to eliminate the personal element in selection and to use some impersonal method. As each plot consisted of 18 rows, each of 22 bushes, it was decided to examine the fourth, eleventh, and eighteenth bush in alternate rows of each plot, commencing with the second, and the tenth bush in the seventeenth row. This rule was rigidly adhered to for each plot. In every plot some bushes were more attacked by borer than others, but it was very unlikely that, by selecting bushes in this fashion, only badly attacked or only lightly attacked bushes would be obtained. On the other hand, it was more probable that there would be a fair proportion of heavily and lightly infested bushes. In this way the personal element in selection was eliminated, and the sample so obtained may be considered to be representative of the whole plot.

The method of examination of the bushes so selected was as follows: The number of branches formed since last pruning were first counted on each bush; small whippy branches, too slender to allow of borer galleries being formed in them, were excluded from the count. Each branch was then carefully searched for galleries and the number recorded. The collar and larger branches up to the last pruning cut were then examined and all galleries counted. An exact record of the number of open galleries present in every bush examined was thus made. The number of branches possessed by the bush having been first obtained, the degree of attack of each bush, i.e., the number of galleries present in relation to the size of the bush, could be calculated.

Reliability of Results.

By dividing the number of galleries in the bush by the number of branches, a figure representing the attack for that bush was obtained. The mean of the twenty-five results so obtained from any one plot gives a value representative of that plot. In column 1 of Table 2 are given the results so obtained from each plot in field A.

It will be seen that the results of the four control (unmanured) plots vary from '632 to '785 galleries per branch. This represents a difference of 24 per cent. between the best and worst control plots. It is obvious, therefore, that plots similarly treated and, as far as can be ascertained, under similar conditions give markedly dissimilar results. Not only do similarly treated plots vary, but the individual bushes in any plot vary amongst themselves. For example, in control plot No. 4, in the 25 bushes examined, the attack varied from '132 to 1·756 galleries per branch, giving an average of '785 galleries per branch. If another 25 bushes were selected at random from the same plot and examined and the results averaged, it would be very improbable that the result obtained would agree closely with the first one of '785 galleries per branch. The more the bushes vary amongst themselves, the greater the difference between the two results would be expected. The question, therefore, arises as to what degree of confidence may be placed in the results recorded.

This, however, is no new problem for the agricultural experimenter. It has frequently been shown by agronomists that the crop yield of similar adjacent plots under similar treatment varies, *i.e.*, of two equal-sized plots with similar soil planted with the same variety of plant and treated exactly alike, the one plot will give a greater yield than the other. There is, therefore, no cause for surprise that large variation exists amongst the control plots of an experiment of this nature, where we are dealing with such a variable character as uniformity of insect attack. But the method used for overcoming the difficulties concerning the variability of crop yields can be advantageously used for interpreting the results of the present experiment.

The method referred to is that known as "probable errors." A full account of the method cannot be given here, but it is hoped that the following brief explanation will convey an intelligible idea of the principles. A probable error (denoted by $\pm E$) has been defined as "a pair of divergencies lying one above and the other below the value determined, and of which we can say with confidence that there is an *even* chance that the true value lies between these limits. These numbers are numerically equal, but one is regarded as plus, the other as minus ($\pm E$), and the two define a range within which, out of a very large number of determinations, at least half the true values would be found."*

* Davenport : "Principles of Breeding."

The probable error of the mean result of each plot of field A has been calculated* and entered in column 2 of Table 2, and also expressed as a percentage of the mean in column 3. It will be seen that plot No. 1 has a mean attack of .632 galleries per branch with a probable error of $\pm .045$ galleries per branch, i.e., with a probable error of ± 7 per cent. of the mean. This means that, if the mean attack in this plot were determined many times by examining further series of 25 bushes, the results of one-half of these determinations may be expected to lie between .587 and .677 (i.e., $.632 \pm .045$) galleries per branch; or, in other words, it is an even chance that the true value for this plot lies within 7 per cent. of the result given, viz., .632 galleries per branch.

By combining the results of the four control plots, a standard is obtained with which each single plot may be compared. It will be noticed that the mean result of the four controls (*average control*) has a probable error of ± 4.5 per cent., a smaller error than that of any single plot. This is due to the fact that the average control is obtained from the results of examination of 100 bushes (25 from each control); consequently, a more accurate result, as shown by a smaller probable error, is expected than when only 25 bushes are used.

In order to ascertain whether the treatment any plot has received has resulted in any improvement as regards Shot-hole Borer attack, the average control has been used as a standard for comparison. The differences between the mean number of galleries per branch of each plot and of the average control are entered in column 4, and expressed as a percentage of the average control in column 5. It will be seen that plot No. 1 has .062 galleries per branch less than the average control, whereas plot No. 3 has .034 galleries per branch more than the average control; plot No. 1 shows an improvement of 8.3 per cent., while in plot No. 3 the attack is 4.9 per cent. worse than the average of the four control plots. In

* The formula used for the calculation of the probable error of the mean is $P. E. \text{ mean} = .6745 \sqrt{\frac{\sigma}{n}}$, where σ represents the standard deviation and n the number of observations. Standard deviation is the square root of the arithmetic mean of the squares of all deviations, deviations being measured from the arithmetic mean of the observations.

Plot No.	Manurial Treatment.	Column 1.		Column 2.		Column 3.		Column 4.		Column 5.		Column 6.		Column 7.		
		Mean Attack.	Probable Error of Mean.	Mean Attack.	Probable Error of Mean.	Galleries per Branch.	Probable Error expressed as Percentage of Mean.	Galleries per Branch.	Probable Error between Plot and Average Control.	Galleries per Branch.	Probable Error of Average Control.	Galleries per Branch.	Probable Error of Average Control.	Galleries per Branch.	Probable Error of Difference.	Difference in Terms of its Probable Error.
1	Nitrate of soda and phosphate	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
2	Cattle manure	...	...	632	± 0.45	...	± 7.0	...	+ 0.62	...	+ 8.9	...	± 8.3	...	+ 1.1	
3	Epox phosphate	...	...	644	± 0.64	...	± 9.9	...	+ 0.50	...	+ 7.2	...	± 10.9	...	+ .7	
4	Control	...	...	728	± 0.67	...	± 9.2	...	— 0.34	...	— 4.9	...	± 10.2	...	— .5	
5	Boga needlos	...	...	785	± 0.61	...	± 7.8	...	— 0.91	...	— 13.1	...	± 9.0	...	— 1.6	(13)
6	Nitrate of potash	...	...	484	± 0.58	...	± 12.0	...	+ 210	...	+ 30.3	...	± 12.8	...	+ 2.4	
7	Control	...	...	618	± 0.49	...	± 7.9	...	+ 0.76	...	+ 10.9	...	± 9.1	...	+ 1.2	
8	Nitrolim	...	...	676	± 0.50	...	± 7.4	...	+ 0.18	...	+ 2.6	...	± 8.7	...	+ .3	
9	Lime	...	...	367	± 0.38	...	± 10.3	...	+ 327	...	+ 47.1	...	± 11.2	...	+ 4.2	
10	Control	...	...	542	± 0.60	...	± 11.1	...	+ 1.62	...	+ 21.9	...	± 12.0	...	+ 1.8	
11	Dedaps	...	...	634	± 0.56	...	± 8.2	...	+ 0.10	...	+ 1.5	...	± 9.3	...	+ .2	
12	Basic slag	...	...	709	± 0.41	...	± 6.8	...	— 0.15	...	— 2.2	...	± 7.3	...	— .3	
13	Control	...	...	694	± 0.44	...	± 6.3	...	0	...	0	...	± 7.7	...	0	
14	Nitrate of soda	...	...	632	± 0.55	...	± 8.7	...	+ 0.62	...	+ 8.9	...	± 9.8	...	+ .9	
15	Muriate of potash	...	...	648	± 0.46	...	± 7.1	...	+ 0.46	...	+ 6.6	...	± 8.4	...	+ .8	
16	Sulphate of ammonia	...	...	672	± 0.53	...	± 9.2	...	+ 1.22	...	+ 17.6	...	± 10.3	...	+ 1.7	
—	Average control	...	...	538	± 0.42	...	± 7.8	...	+ 1.56	...	+ 22.5	...	± 9.0	...	+ 2.5	
—	...	...	...	694	± 0.31	...	± 4.5	...	—	...	—	...	—	...	—	

columns 4 and 5, where the difference signifies an improvement, a plus (+) sign is used throughout; to denote the reverse a minus (—) sign is used. The probable errors of the differences shown in column 5 have been calculated* and entered in column 6.

It will be remembered from the definition of "probable errors," that the chances are even, that any error involved will lie within the limits set by the probable error. There is, of course, also an even chance that the true value lies outside the same limits, but, the following table will show that it is very unlikely that the error is many times as great as the probable error ($\pm E$). Thus, the chances that the true value lies *within* the range set by $\pm E$, $\pm 2E$, &c., are as follows†:—

$\pm E$ the chances are	even
$\pm 2E$	4·5 to 1
$\pm 3E$	21 to 1
$\pm 4E$	142 to 1
$\pm 5E$	1,310 to 1
$\pm 6E$	19,200 to 1
$\pm 7E$	420,000 to 1
$\pm 8E$	17,000,000 to 1

It is therefore improbable that an error will be many times as large as the probable error. For instance, it is practically certain that the error is not as large as eight times the probable error, since the table shows that the chances are about 17 millions to one in favour of its being smaller than 8E.

Turning again to Table 2, it will be seen that although plot No. 1 shows an improvement of 8·9 per cent, over the average control, yet the probable error of this difference is 8·3 per cent., i.e., the probable error is almost as great as the improvement shown. Obviously, therefore, this improvement cannot be

* The probable error in a difference may be taken to be the square root of the sum of the squares of the probable errors of the two results.

† Davenport: *loc. cit.*

considered to be definite. On the other hand, plot No. 8 shows an improvement of 47·1 per cent., with a probable error of 11·2 per cent., *i.e.*, the improvement is more than four times as great as its probable error, and from the table of chances quoted above, it will be seen that the chances are more than 142 to 1 that this improvement is real, and not due to experimental errors.

It has become the general practice in agricultural cropping experiments to accept odds of 30 to 1 as amounting to certainty, *i.e.*, any improvement to be considered significant must be at least 3·2 times as great as its probable error ($\pm E$). It must be pointed out that odds of 30 to 1 are on the low side rather than the contrary. To show that this is the case, a statement of Reitz and Smith concerning the significance of probable errors* is quoted: "If the difference between two results does not exceed 2 or 3 times the probable error, the difference may reasonably be attributed to random sampling. If the difference between two results is as much as 5-10 times the probable error, the probability of such differences in random sampling is so small that we are justified in saying that the difference is significant. In fact, a difference of 10 times its probable error is certainly significant in so far as there is certainty in human affairs." It will be seen from this statement that before a difference can be considered certainly significant, it must be at least 5 times as great as its probable error; converting into odds, it will be seen from the above table that odds of 1,310 to 1 are demanded as amounting to certainty.

Following, however, the general practice in agricultural experiments, and accepting odds of 30 to 1 as amounting to certainty (*i.e.*, accepting any improvement 3·2 times as great as the probable error as significant), it will be seen from column 7 of Table 2, in which the improvement is expressed in terms of the probable error (obtained by dividing the differences in column 5 by the probable errors in column 6), that plot No. 8 (nitrolim), which shows an improvement 4·2 times as great as its probable error, is the only plot showing a sufficiently great improvement to be considered significant.

Discussion of Results.

The results of examination of fields B and C have been tabulated and analysed in Tables 3 and 4 respectively, as were those of field A in Table 2. It will be noticed that the attack

* Babcock and Clausen : "Genetics in relation to Agriculture."

Table 3.—FIELD B.

Plot No.	Manorial Treatment.	Column 1.	Column 2.	Column 3.	Column 4.	Column 5.	Column 6.	Column 7.
		Mean Attack.	Probable Error of Mean.	Probable Error expressed as Percentage of Mean.	Difference between Plot and Average Control.	Difference as Percentage of Average Control.	Probable Error of Difference.	Difference in Terms of Probable Error.
		Galleries per Branch.	Galleries per Branch.	Per Cent.	Galleries per Branch.	Per Cent.	Per Cent.	Per Cent.
1	Nitrate of soda and phosphate	1.216 ..	± .067 ..	± 5.5 ..	— .077 ..	— 6.8 ..	± 6.0 ..	— 0.1
2	Cattle manure	1.071 ..	± .052 ..	± 4.9 ..	+ .068 ..	+ 6.0 ..	± 5.6 ..	+ 1.1
3	Ephos phosphate	1.007 ..	± .061 ..	± 6.1 ..	+ .132 ..	+ 11.6 ..	± 6.6 ..	+ 1.8
4	Control	1.004 ..	± .063 ..	± 6.3 ..	+ .135 ..	+ 11.8 ..	± 6.8 ..	+ 1.7
5	Boga medelos	.925 ..	± .056 ..	± 6.1 ..	+ .214 ..	+ 18.8 ..	± 6.6 ..	+ 2.8
6	Nitrate of potash	1.413 ..	± .069 ..	± 4.9 ..	— .274 ..	— 24.1 ..	± 5.5 ..	— 4.4
7	Control	1.103 ..	± .063 ..	± 5.7 ..	+ .036 ..	+ 3.2 ..	± 6.2 ..	+ .6
8	Nitrolim	1.098 ..	± .070 ..	± 6.4 ..	+ .041 ..	+ 3.6 ..	± 6.9 ..	+ .5
9	Lime	.918 ..	± .045 ..	± 4.9 ..	+ .221 ..	+ 19.4 ..	± 5.5 ..	+ 3.5
10	Control	1.342 ..	± .058 ..	± 4.3 ..	— .203 ..	— 17.8 ..	± 5.0 ..	— 3.6
11	Dedaps	.988 ..	± .044 ..	± 4.5 ..	+ .151 ..	+ 13.3 ..	± 5.1 ..	+ 2.6
12	Basic slag	1.213 ..	± .053 ..	± 4.4 ..	— .074 ..	— 6.5 ..	± 5.1 ..	— 1.3
13	Control	1.108 ..	± .046 ..	± 4.2 ..	+ .031 ..	+ 2.7 ..	± 4.9 ..	+ .6
14	Nitrate of soda	.833 ..	± .049 ..	± 5.9 ..	+ .306 ..	+ 26.8 ..	± 6.4 ..	+ 4.2
15	Muriate of potash	1.067 ..	± .043 ..	± 4.0 ..	+ .072 ..	+ 6.3 ..	± 4.7 ..	+ 1.3
16	Sulphate of ammonia	.858 ..	± .039 ..	± 4.6 ..	+ .281 ..	+ 24.7 ..	± 5.1 ..	+ 4.8
—	Average control	1.139 ..	± .028 ..	± 2.5 ..	— ..	— ..	— ..	— ..

Table 4.—FIELD C.

Plot No.	Manurial Treatment.	Column 1.	Column 2.	Column 3.	Column 4.	Column 5.	Column 6.	Column 7.
		Mean Attack.	Probable Error of Mean.	Probable Error expressed as Percentage of Mean.	Difference between Plot and Average Control.	Probable Error of Average Control.	Difference in Terms of its Probable Error.	
		Galleries per Branch.	Galleries per Branch.	Galleries per Branch.	Galleries per Branch.	Galleries per Branch.	Per Cent.	Per Cent.
1	Nitrate of soda and phosphos	..	.141 ..	± .033 ..	± .23.4 ..	— .022 ..	± 18.5 ..	± 24.5 ..
2	Cattle manure ..	..	.129 ..	± .012 ..	± 9.3 ..	— .010 ..	± 8.4 ..	— .11.9 ..
3	Epitos phosphate ..	..	.150 ..	± .024 ..	± 16.0 ..	— .031 ..	± 26.0 ..	— .17.6 ..
4	Control ..	..	.092 ..	± .023 ..	± 25.0 ..	— .027 ..	± 22.7 ..	— .17.0 ..
5	Boga medelos ..	..	.249 ..	± .043 ..	± 17.3 ..	— .130 ..	— .109.2 ..	— .18.8 ..
6	Nitrate of potash ..	..	.106 ..	± .022 ..	± 20.7 ..	— .013 ..	± 10.9 ..	— .22.0 ..
7	Control ..	..	.094 ..	± .012 ..	± 12.8 ..	— .025 ..	± 21.0 ..	— .14.9 ..
8	Nitrolim ..	..	.179 ..	± .024 ..	± 13.4 ..	— .060 ..	— 50.4 ..	— .15.3 ..
9	Lime ..	..	.161 ..	± .022 ..	± 13.7 ..	— .042 ..	— 35.3 ..	— .15.6 ..
10	Control ..	..	.162 ..	± .017 ..	± 10.6 ..	— .043 ..	— 36.1 ..	— .12.8 ..
11	Dadaps ..	..	.089 ..	± .015 ..	± 16.9 ..	— .030 ..	— 25.2 ..	— .18.4 ..
12	Basic slag ..	..	.221 ..	± .025 ..	± 11.3 ..	— .102 ..	— 85.7 ..	— .13.5 ..
13	Control ..	..	.126 ..	± .015 ..	± 11.9 ..	— .007 ..	— 5.9 ..	— .14.0 ..
14	Nitrate of soda ..	..	.164 ..	± .022 ..	± 13.4 ..	— .045 ..	— 37.8 ..	— .15.3 ..
15	Muriate of potash ..	..	.137 ..	± .021 ..	± 15.3 ..	— .018 ..	— 15.1 ..	— .17.0 ..
16	Sulphate of ammonia ..	..	.137 ..	± .017 ..	± 12.4 ..	— .018 ..	— 15.1 ..	— .14.4 ..
— ..	Average control ..	..	.119 ..	± .009 ..	± 7.4 ..	— ..	— ..	— ..

in field B is the most severe, the mean attack of the average control being 1.139 galleries per branch, against .694 and .119 of fields A and C respectively. This does not necessarily mean that it is during the second year from pruning that bushes are most severely attacked, as the difference in attack may be due more to the locality of the field than to the age of the bushes from pruning. In fact, it was known, before the experiments were begun, that field B was usually the most severely attacked of the three.

It has already been shown that the nitrolim plot in field A is the only plot of that field which shows an improvement which may be considered significant, even when the low odds usual with agricultural experiments are accepted. Also no plot in the same field is sufficiently badly attacked to be considered definitely worse than the average control.

In field B the results are somewhat different. The nitrolim plot here shows an improvement over the average control of only 3.6 per cent., an amount smaller by half than the experimental error, and consequently of no significance. On the other hand, the sulphate of ammonia, nitrate of soda, and lime plots have given results indicative of a definite reduction of Shot-hole Borer attack as a result of treatment. The nitrate of potash plot was the most severely attacked manured plot in this field, showing an attack greater by 24 per cent. than that of the average control. In field A this plot was less heavily attacked than the average control.

In field C two manured plots, viz., dadaps and nitrate of potash, showed improvements over the average control, and these improvements were small in comparison with their probable errors. On the other hand, the basic slag and boga medeloa plots were very badly attacked in comparison with the average control, the borer galleries being 109 per cent and 85 per cent. respectively more prevalent.

It will be seen that the plot results of the three fields are very dissimilar, no manure giving consistently good results in all three fields. Also in no field does any manured plot show an improvement as regards Shot-hole Borer attack sufficiently great compared with its probable error to be really significant according to the standard of Reitz and Smith (*i.e.*, that the improvement must be five times as great as its probable error to denote significance). Attack by Shot-hole Borer through a field or plot is much less uniform than is the cropping capacity of individual experimental plots, and it would appear that odds of 30 to 1, usually accepted

by agricultural workers as denoting significance with cropping results, are too small to be accepted when dealing with the more variable character of insect attack.

Table 5.

Plot No.	Manurial Treatment.	Column 1.	Column 2.	Column 3.	Column 4.	Column 5.
		Field A.	Field B.	Field C.	Mean of Three Results.	Order of Merit.
1 ..	Nitrate of soda and ephos phosphate	91·1 ..	106·8 ..	118·5 ..	105·5 ..	15
2 ..	Cattle manure	92·8 ..	94·0 ..	108·4 ..	98·4 ..	6
3 ..	Ephos phosphate	104·9 ..	88·4 ..	126·0 ..	106·4 ..	13
4 ..	Control	113·1 ..	88·2 ..	77·3 ..	99·5 ..	7
5 ..	Boga medeloa	69·7 ..	81·2 ..	209·2 ..	120·0 ..	15
6 ..	Nitrate of potash	89·1 ..	124·1 ..	89·1 ..	100·8 ..	10
7 ..	Control	97·4 ..	96·8 ..	79·0 ..	91·1 ..	3
8 ..	Nitrolim	52·9 ..	96·4 ..	150·4 ..	99·9 ..	8
9 ..	Lime	78·1 ..	80·6 ..	135·3 ..	98·0 ..	4
10 ..	Control	98·5 ..	117·8 ..	136·1 ..	117·5 ..	14
11 ..	Dadaps	102·2 ..	86·7 ..	74·8 ..	87·9 ..	1
12 ..	Basic slag	100·0 ..	106·5 ..	185·7 ..	130·7 ..	16
13 ..	Control	91·1 ..	97·3 ..	105·9 ..	98·1 ..	5
14 ..	Nitrate of soda	93·4 ..	73·2 ..	137·8 ..	101·5 ..	11
15 ..	Muriate of potash	82·4 ..	93·7 ..	115·1 ..	100·4 ..	9
16 ..	Sulphate of ammonia	77·5 ..	75·3 ..	115·1 ..	89·3 ..	2
— ..	<i>Average control</i>	100·0 ..	100·0 ..	100·0 ..	100·0 ..	—

Table 5 shows the relative attacks for all plots of each field, the attack of the average control of each field being taken as 100. From this table it will be seen that the attack of plot No. 1 of fields A, B, and C is 91·1, 106·8, and 118·5, respectively, against an average control of 100 in each case. The mean of these three results is given in column 4 as 105·5, i.e., 5·5 per cent. worse than the mean of the average controls. From the mean results given in column 4 it is evident that borer attack in the dadap and sulphate of ammonia plots is on the average less than that of other plots. Control plot No. 7, however, comes next with 91·1. Though the average dadap plot shows an improvement of 12 per cent. over the average control plots, yet it is only about 3 per cent. better than the best controls (No. 7), and therefore cannot be

considered to be decisively better than that of the unmanured plots. Basic slag (130·7), boga medeloa (120·0), and control plot No. 10 (117·5) have given the worst results. Basic slag gives a result about 13 per cent. worse than the worst unmanured plot. It should not be concluded, however, that this manure encourages borer attack.

It must, however, be pointed out that the probable error of observations made on the plots in field C is greater than that of observations made in fields A and B, as may be seen from Tables 2, 3, and 4. Owing to this difference in size of probable errors, though in field B an improvement of 20 per cent. may indicate significance, an improvement of nearly 50 per cent. would be required in field C. Consequently the value 150 in field C is equivalent to about 120 in field B. This results in very high and very low attack values of field C unduly influencing the mean result of the three fields as given in Table 5. The mean results of the individual control plots, however, are similarly affected, and so fairly reliable comparisons can be made between the manured and unmanured plots, though the relative values of the manurial plots may not be very accurate.

Table 6.

Plot No.	Manurial Treatment.	Column 1.	Column 2.	Column 3.	Column 4.	Column 5.	Mean of Three Results. Order of Merit.
		Field A.	Field B.	Field C.			
1 ..	Nitrate of soda and ephos phosphate.	1·1 ..	1·1 ..	·8 ..	·3 ..	13	
2 ..	Cattle manure	·7 ..	1·1 ..	·7 ..	·4 ..	8	
3 ..	Ephos phosphate	·5 ..	1·8 ..	1·5 ..	·1 ..	11	
4 ..	Control	..	1·5 ..	1·7 ..	·9 ..	·4 ..	8
5 ..	Boga medeloa	2·4 ..	2·8 ..	5·8 ..	·2 ..	12	
6 ..	Nitrate of potash	1·2 ..	4·4 ..	·5 ..	·9 ..	14	
7 ..	Control	..	·3 ..	·5 ..	1·4 ..	·7 ..	5
8 ..	Nitrolim	..	4·2 ..	·5 ..	3·3 ..	·5 ..	7
9 ..	Lime	..	1·8 ..	3·5 ..	2·3 ..	1·0 ..	3
10 ..	Control	..	·2 ..	3·6 ..	2·8 ..	2·1 ..	15
11 ..	Dadaps	..	·3 ..	2·6 ..	1·4 ..	1·2 ..	2
12 ..	Basic slag	..	·0 ..	1·3 ..	6·3 ..	2·5 ..	16
13 ..	Control	..	·9 ..	·6 ..	·4 ..	·4 ..	8
14 ..	Nitrate of soda	..	·8 ..	4·2 ..	2·5 ..	·8 ..	4
15 ..	Muriate of potash	1·7 ..	1·3 ..	·9 ..	·7 ..	6	
16 ..	Sulphate of ammonia	2·5 ..	4·8 ..	1·0 ..	2·1 ..	1	

Another method of combining the results of these experiments by which the effect of the varying probable errors might be eliminated was therefore resorted to. In column 7 of Tables 2, 3, and 4 the difference between each plot result and that of the average control in terms of its probable error is given. It would appear that by combining the results there given for each plot a more accurate order of merit might be obtained. In columns 1, 2, and 3 of Table 6 the results given in column 7 of Tables 2, 3, and 4, respectively, have been entered, and the mean of the three results is given in column 4. Where a difference indicates an improvement, its value in terms of its probable error has been considered to be a positive quantity, whereas if the reverse is indicated, its value has been considered to be negative. From the values given in column 4 an order of merit has been obtained and entered in column 5. If this order be compared with the order previously obtained from Table 4, it will be seen that a few changes have occurred. The best series of control plots (No. 7) drops to the fifth place, and in addition to the dadap and sulphate of ammonia plots, the lime and nitrate of soda plots precede it. The worst individual control plot (No. 10) falls to the fifteenth place, leaving only the basic slag plot below it. If the values given in column 4 are converted into odds by the table given on page 14, it will be seen that the odds in favour of the mean result of the best plot (sulphate of ammonia) being significant are only about 5 : 1, odds much smaller than those demanded in agricultural experiments. Similarly, the mean result of the basic slag plots is not significantly worse than the average control. In short, no single manure has given results decisively better or worse than the unmanured plots as regards the number of galleries in the bushes.

Contents of Galleries.

The beetle, having bored its gallery, should it find the conditions there unsuitable for raising its normal brood, is compelled either to leave the gallery and start again elsewhere, or to raise a smaller brood. When once the gallery has been formed, the primary damage to the tea bush is complete, as the branch containing the gallery has thereby been weakened, and so is liable to break. If, however, a large brood is raised in each gallery, there will be emerging in the course of time large numbers of adult beetles, of which the females in their turn will form galleries and so damage branches. A reduction

in the size of a brood is therefore equivalent to a reduction of the future attack. It was, therefore, necessary to make examinations of galleries from each plot in order to obtain accurate information as to the proportion of galleries deserted, and the average number of mature or immature beetles contained in the occupied galleries.

For this purpose a number of branches from each plot was removed during the final examination. These galleries were carefully opened and their contents recorded. Adults, pupæ, larvae, and eggs of each gallery were counted separately. Summaries of the results for the plots of fields A, B, and C are given in Tables 7, 8, and 9, respectively.

Table 7.—FIELD A.

Plot No.	Manurial Treatment.	Number of Galleries.			Contents of Galleries.					Mean Content per Occupied Gallery.	
		Examined.	Empty.	Occupied.	Percentage of Galleries Empty.	Adults.	Pupæ.	Larvae.	Eggs.		
1	Nitrate of soda and ephos phosphate	25	8	17	32	24	4	26	5	59	3.5
2	Cattle manure	25	9	16	36	22	3	38	12	75	4.7
3	Ephos phosphate	25	7	18	28	28	1	15	5	49	2.7
4	Control	25	7	18	28	27	12	35	3	77	4.3
5	Boga medeloa	25	9	16	36	21	3	25	10	59	3.7
6	Nitrate of potash	25	6	19	24	31	8	35	6	80	4.2
7	Control	25	6	19	24	35	6	30	11	82	4.3
8	Nitrolim	25	6	19	24	23	5	17	17	62	3.3
9	Lime	25	7	18	28	24	0	10	7	41	2.3
10	Control	25	6	19	24	25	11	33	1	70	3.7
11	Dadaps	25	8	19	24	25	4	19	5	52	2.8
12	Basic slag	25	7	18	28	29	8	30	6	73	4.1
13	Control	25	5	20	20	30	8	34	7	79	3.9
14	Nitrate of soda	25	8	17	32	25	1	17	2	45	2.6
15	Muriate of potash	25	7	18	28	27	4	31	16	75	4.3
16	Sulphate of ammonia	25	11	14	44	22	1	21	2	46	3.3
	<i>Average control</i>	<i>100</i>	<i>24</i>	<i>76</i>	<i>24</i>	<i>117</i>	<i>37</i>	<i>132</i>	<i>32</i>	<i>308</i>	<i>4.1</i>

It will be seen from the figures given for the mean of the four control plots (*average control*) that the percentage of empty galleries increases with the age of the bushes from last pruning, the percentages being 12, 16, and 24 for the fields C, B, and A, respectively. This is what might be expected from the facts that the bushes are least liable to attack at

the time when new shoots begin to appear after pruning, and that increase of attack takes place from about the ninth month after pruning until the time of next pruning. With increased time more broods reach maturity and more galleries become deserted.

There does not appear to be any relationship between the mean content per occupied gallery of the three fields. The mean content of occupied galleries from all the unmanured

Table 8.—FIELD B.

Plot No.	Manurial Treatment.	Number of Galleries.			Contents of Galleries.					Mean Content per Occupied Gallery.	
		Examined.	Empty.	Occupied.	Percentage of Galleries Empty.	Adults.	Pupæ.	Larvæ.	Eggs.		
1	Nitrate of soda and ephos phosphate	50	14	36	28	50	7	25	8	90	2.5
2	Cattle manure	50	16	34	32	50	2	31	15	98	2.9
3	Ephos phosphate	50	7	43	14	71	8	51	16	146	3.4
4	Control	50	7	43	14	74	4	26	6	110	2.6
5	Boga medeloa	50	10	40	20	68	9	56	14	147	3.7
6	Nitrate of potash	50	13	37	28	70	8	77	13	168	4.5
7	Control	50	6	44	12	74	3	37	7	121	2.7
8	Nitrolim	50	17	33	34	60	5	29	13	107	3.2
9	Lime	50	10	40	20	66	3	29	18	116	2.9
10	Control	50	10	40	20	70	9	47	13	130	3.5
11	Dadaps	50	10	40	20	62	8	64	14	148	3.7
12	Basic slag	50	15	35	30	64	17	55	28	164	4.7
13	Control	50	9	41	18	53	5	33	27	118	2.9
14	Nitrate of soda	50	19	31	38	42	2	29	19	92	3.0
15	Muriate of potash	50	14	36	28	61	10	36	17	124	3.4
16	Sulphate of ammonia	50	16	34	32	42	3	24	9	78	2.3
—	Average control	200	32	168	16	271	21	143	53	488	2.8

plots of field B is 2.8 compared with 4.1 and 5.5 of fields A and C, respectively. In calculating the mean content of galleries, eggs, larvæ, and pupæ are totalled with the adults, as it is only a matter of time before they become beetles. It was expected that the mean content per occupied gallery, when calculated from a large number of galleries, would be fairly constant. It would appear, however, that some factor unknown influences the average gallery content, and that the galleries in field B have been so affected.

This raises the question as to what is the normal content of a gallery. Speyer* gives the following data :—

Maximum number of young individuals found in one gallery 34
Average number of young individuals found in one gallery 15

The average number of young individuals found in one gallery is much larger than that obtained during the present investigations. In these experiments the average number of

Table 9.—FIELD C.

Plot No.	Manurial Treatment.	Number of Galleries.			Percentage of Galleries Empty.	Contents of Galleries.				Mean Content per Occupied Gallery.	
		Examined.	Empty.	Occupied.		Adults.	Pupae.	Larvae.	Eggs.		
1	Nitrate of soda and ephos phosphate	25	2	23	8	45	21	58	21	145	6.3
2	Cattle manure	18	2	16	11	31	12	43	7	93	5.8
3	Ephos phosphate	17	2	15	12	20	11	57	2	90	6.0
4	Control	14	3	11	21	16	1	21	10	48	4.4
5	Boga medeloa	25	2	23	8	48	27	68	7	150	6.5
6	Nitrate of potash	17	3	14	18	22	3	17	2	44	3.2
7	Control	20	2	18	10	26	15	53	11	105	5.8
8	Nitrolim	16	0	16	0	24	8	51	11	94	5.9
9	Lime	25	2	23	8	40	7	30	5	82	3.6
10	Control	25	3	22	12	39	4	68	16	127	5.8
11	Dadaps	15	1	14	7	22	5	58	8	93	6.6
12	Basic slag	21	2	19	10	25	3	50	23	101	5.3
13	Control	23	2	21	9	32	6	44	34	116	5.5
14	Nitrate of soda	25	5	20	20	34	6	33	15	88	4.4
15	Muriate of potash	21	4	17	19	21	2	32	18	73	4.3
16	Muriate of ammonia	24	3	21	12	30	6	22	18	76	3.6
	Average control	82	10	72	12	113	26	186	71	396	5.5

individuals, young and old, found in an occupied gallery was 3.8. The greatest number of individuals, including eggs, in any one gallery was thirty-seven, agreeing fairly closely with the number given by Speyer. The average number of eggs laid by a female would appear to be about fifteen, and possibly this is what Speyer means when he gives 15 as being the average number of young individuals found in one gallery. Examinations of fields A and C show that the average content of an occupied gallery is about five, but the galleries in field B have an average content slightly more than half this amount.

* "The Shot-hole Borer Investigation," Leaflet issued by the Department of Agriculture, Ceylon, November, 1916.

Proportion of Empty Galleries.

In Tables 10 and 11 the results given for each plot in Tables 7, 8, and 9 have been combined. In Table 10 the number of empty galleries from each series of three plots similarly treated is expressed as a percentage of the total number examined. Of the 382 galleries from all the control plots of the three fields, 17.3 per cent. were found to be empty. The best result from the manured plots was obtained from the nitrate of soda plot, with 32 per cent. empty galleries. Of every 100 galleries examined, 17.3 were found to be empty in the control plots, against 32 in the nitrate of soda plot.

Table 10.

Plot No.	Manurial Treatment.	Number of Galleries examined.	Number of Empty Galleries.	Percentage of Galleries found Empty.	Order of Merit.
1 . . .	Nitrate of soda and ephos phosphate	100	24	24	7
2 . . .	Cattle manure	93	27	29	3
3 . . .	Ephos phosphate	92	16	17.4	14
4 . . .	Control	89	17	19.1	10
5 . . .	Boga medeloa	100	21	21	9
6 . . .	Nitrate of potash	92	22	23.9	8
7 . . .	Control	95	14	14.7	16
8 . . .	Nitrolim	91	23	25.3	5
9 . . .	Lime	100	19	19	11
10 . . .	Control	100	19	19	11
11 . . .	Dadaps	90	17	18.9	13
12 . . .	Basic slag	96	24	25	6
13 . . .	Control	98	16	16.3	15
14 . . .	Nitrate of soda	100	32	32	1
15 . . .	Muriate of potash	96	25	26	4
16 . . .	Sulphate of ammonia	99	30	30.3	2
— . . .	Average control	382	66	17.3	—

The question then arises as to whether the greater number of empty galleries found in the nitrate of soda plots is significant of some real difference, or whether it has arisen solely as an error of sampling. If the proportion of empty galleries was really the same in the nitrate of soda plots as in the control plots, would it be probable that a difference, such as was found between the two proportions, would arise merely as a fluctuation of simple sampling?

If from a bag containing 1,000 small balls, half of which were white and the other half black, 100 balls are withdrawn at random, we would expect 50 to be white and 50 to be black. It is unlikely that only white balls or only black ones would be withdrawn in the sample; it is most likely that the proportion of white and black balls would approximate 50 : 50. The larger the sample taken, the more likely is the proportion 50 : 50 to be obtained. If these balls are returned to the bag

and another sample of 100 withdrawn, it is again unlikely that the proportion will differ to any great extent from the theoretical 50 : 50, though it may differ somewhat from the value observed in the first sample. The difference observed in the proportions of the two samples is obviously due to "an error in sampling" or to a "fluctuation of simple sampling." A similar error is bound to occur in sampling Shot-hole Borer galleries to determine whether they are empty or occupied. The proportion of empty galleries obtained by such sampling is not necessarily the true value, but it will approximate it more or less closely, according as the sample taken is large or small.

In the experiment with the coloured balls, we knew that the proportion of black to white balls in the bag was 50 : 50. In sampling the Shot-hole Borer galleries, we do not know what the true proportion of empty to occupied galleries is, nor do we know that the true proportions are the same in the nitrate of soda plots as in the control and other plots. The difference observed between the proportions of empty galleries of any two plots may be due either to an error in sampling, to a difference in the true proportions of empty galleries for the plots, or to both these factors. It is necessary to determine, therefore, whether the difference between the results obtained from the nitrate of soda plots and the control plots is too great to be due merely to sampling, or whether the difference is more likely to be due to there being a greater proportion of empty galleries in the former than the latter plots.

If we assume that the true proportion of empty galleries is the same for both series of plots, and that its true value is given by the (weighted) mean proportion in our two results, then it may be calculated* that, if the observed difference is less than 13·6 per cent., it may have arisen as a fluctuation of simple sampling only. As the observed difference between the nitrate of soda plots is 14·7 per cent., it is therefore probable that this difference is not due to an error of sampling alone.

If, on the other hand, we assume that the proportion of empty galleries is not the same in the nitrate of soda plots as in the control plots, but that the values observed (*i.e.*, 32 and 17·3 per cent. respectively) are the true values of the proportions, it may be calculated† that an error of simple

* The calculation has been made from the following formula given by Yule in "An Introduction to the Theory of Statistics." 5th ed. (1919), p. 269 $\epsilon^2_{12} = p_0 q_0 \left(\frac{1}{n_1} + \frac{1}{n_2} \right)$

† Yule : *loc. cit.* $\epsilon^2_{12} = \frac{p_1 q_1}{n_1} + \frac{p_2 q_2}{n_2}$

sampling, on taking fresh samples from the same plots, may amount to 15 per cent. Thus, the error of sampling under the conditions of this experiment would be just sufficiently great to obliterate a real difference of 14.7 per cent. in the proportions of empty galleries between the two plots.

The difference of 14.7 per cent. between the proportions of empty galleries found in the nitrate of soda and control plots would indicate that this is a real difference, and not due to an error of sampling. The manurial plots giving the next best results are the sulphate of ammonia, with an improvement of 13 per cent. over the controls. These two manures—both nitrogenous—are the only two which may be considered to have shown significant results as regards the proportions of empty galleries found, as compared with the control plots.

Mean Content of Occupied Galleries.

From Table 11 it will be seen that the mean content of the occupied galleries from all the control plots (*average control*) is 3.77. The series of control plots with the smallest mean content is No. 4, with 3.26 individuals per gallery. Only two series of the treated plots, viz., the sulphate of ammonia and lime plots, have fewer individuals per gallery than this series of controls. The difference between the mean content per occupied gallery of the sulphate of ammonia plots and the average control is .87 individuals. Is this difference really significant, or could it arise purely as an experimental error?

Table 11.

Plot No.	Manurial Treatment.	Number of Total Galleries occupied.	Content per Order of Merit.	Mean Content per Occupied Gallery.
1 ..	Nitrate of soda and ephos phosphate	76 .. 294	3.87 ..	8
2 ..	Cattle manure	66 .. 266	4.04 ..	12
3 ..	Ephos phosphate	76 .. 285	3.75 ..	5
4 ..	Control	72 .. 235	3.26 ..	3
5 ..	Boga medeloa	79 .. 356	4.52 ..	15
6 ..	Nitrate of potash	70 .. 292	4.17 ..	14
7 ..	Control	81 .. 308	3.80 ..	7
8 ..	Nitrolim	68 .. 263	3.87 ..	8
9 ..	Lime	81 .. 239	2.95 ..	2
10 ..	Control	81 .. 336	4.15 ..	13
11 ..	Dadaps	73 .. 294	4.03 ..	11
12 ..	Basic slag	72 .. 338	4.70 ..	16
13 ..	Control	82 .. 313	3.83 ..	6
14 ..	Nitrate of soda	68 .. 225	3.31 ..	4
15 ..	Muriate of potash	71 .. 275	3.87 ..	8
16 ..	Sulphate of ammonia	69 .. 200	2.90 ..	1
— ..	<i>Average control</i>	316 .. 1,192	3.77 ..	—

The probable error of the results obtained from the sulphate of ammonia plots and the average control have been calculated to be $\pm .33$ and $\pm .17$ individuals per gallery respectively. It is therefore even chances that the mean content of the galleries in the sulphate of ammonia plots lies between 2.67 and 3.13 , and of the average control between 3.60 and 3.94 individuals. The probable error of the difference between the two results is $\pm .37$. The difference, being $.87$, is consequently 2.3 times as great as its probable error. This, from the table of odds given on page 14, will be seen to represent odds of only about 7 to 1 against it, being due solely to experimental error. Consequently, the smaller mean content of the galleries in the sulphate of ammonia plots cannot be regarded as conclusive proof that the galleries of those plots contain throughout a smaller number of individuals than do the galleries of the control plots, as the difference actually found may have arisen as an error of sampling. The smaller differences shown by the other manurial plots in all probability have also arisen as experimental errors. There is, therefore, insufficient evidence to show that any manurial treatment has resulted in a reduction of the mean number of individuals found in the occupied galleries.

General Discussion.

The measurement of Shot-hole Borer attack has been viewed from three different standpoints, viz.: (1) The number of galleries present in the bush; (2) the proportion of galleries which are occupied or empty; and (3) the number of individuals present in the occupied galleries. No single manurial treatment has given results which may be considered conclusive from each viewpoint considered separately.

Fields in which the bushes contain numerous galleries, of which a small proportion are empty, and of which the occupied ones contain many individuals, will in the near future be more severely attacked than others in which the bushes have a similar number of galleries but of which a large proportion are empty, and those which are occupied contain few individuals. The latter fields, if examined later, would show a smaller number of galleries than would the former, as fewer beetles are being raised to bore the galleries. The ultimate value of a manure as a control of Shot-hole Borer can, therefore, best be determined when its effect in the three ways mentioned above are considered simultaneously.

Some idea of the relative values of the various manures as controls for Shot-hole Borer, when considered from the three viewpoints simultaneously, may be obtained by taking the

mean of the orders of merit for the various plots given in Tables 6, 10, and 11. In Table 12 the mean order of merit for the various plots, from which a final order of merit has been derived, is given. It will be seen that the best series of control plots (No. 4) takes fifth place, and that control plots No. 13 occupy the sixteenth. Of the five treatments which have given results better than control plots No. 4, three are nitrogenous manures, viz., sulphate of ammonia, nitrate of soda, and nitrolim, the remaining two being lime and muriate of potash.

Table 12.

Plot No.	Manurial Treatment.	Order of Merit from Table 6, Table 9, Table 10.				Mean.	Final Order of Merit.
1 ..	Nitrate of soda and ophos phosphate	13	..	7	..	8 ..	9.3 .. 8
2 ..	Cattle manure ..	8	..	3	..	12 ..	7.6 .. 7
3 ..	Ephos phosphate ..	11	..	14	..	5 ..	10.0 .. 10
4 ..	Control ..	8	..	10	..	3 ..	7.0 .. 6
5 ..	Boga medeloa ..	12	..	9	..	15 ..	12.0 .. 11
6 ..	Nitrate of potash	14	..	8	..	14 ..	12.0 .. 11
7 ..	Control ..	5	..	16	..	7 ..	12.8 .. 14
8 ..	Nitrolim ..	7	..	5	..	8 ..	6.8 .. 5
9 ..	Lime ..	3	..	11	..	2 ..	5.3 .. 3
10 ..	Control ..	15	..	11	..	13 ..	13.0 .. 16
11 ..	Dadaps ..	2	..	13	..	11 ..	12.0 .. 11
12 ..	Basic slag ..	16	..	6	..	16 ..	12.8 .. 14
13 ..	Control ..	8	..	15	..	6 ..	9.6 .. 9
14 ..	Nitrate of soda ..	4	..	1	..	4 ..	3.0 .. 2
15 ..	Muriate of potash	6	..	4	..	8 ..	6.0 .. 4
16 ..	Sulphate of ammonia ..	1	..	2	..	1 ..	1.3 .. 1

The best result was obtained with sulphate of ammonia. This manure has given consistent results in the three fields. In only one of the nine determinations made, viz., that of the number of galleries per branch in field C, has it given a result inferior to that obtained as an average of the control plots. Nitrate of soda has given almost equally good results. The results obtained from the other nitrogenous manure, viz., nitrolim, are very little better than those obtained from control plots No. 4.

Though the potassic plot (No. 5) gives the fourth best result, yet plot No. 6, which received nitrogen and potash in the form of nitrate of potash, gives a result on the whole no better than the unmanured plots.

The remaining plots, with the exception of lime plots (No. 9), have given no indication that they have received any benefit from their treatment as regards Shot-hole Borer attack.

It may, therefore, be concluded that, though these experiments have given no conclusive results, they indicate that, of the manurial substances tried, the simple nitrogenous manures, particularly sulphate of ammonia and nitrate of soda, have a beneficial effect in controlling Shot-hole Borer. Lime, too, appears to be beneficial in this respect. The methods used in these experiments have given rise to experimental errors of considerable size, but it should be possible, with the information and experience gained from these preliminary experiments, to lay out plots from which conclusive results might be obtained.

Summary.

The foregoing experiments are of a preliminary nature, and were carried out to ascertain what manurial substances, if any, have a controlling effect on Shot-hole Borer, and to determine, if possible, how this control is carried out.

As the application of manures, by increasing the vigour of the bushes, tends to obscure the damage done by the beetles and so lead to a false idea as to the prevalence of the borer, some method had to be devised to measure with some degree of accuracy the intensity of Shot-hole Borer attack.

By sampling in each plot to ascertain (1) the average number of galleries per branch, (2) the proportion of empty galleries, and (3) the mean number of individuals, including adults, pupæ, larvæ, and eggs, in the occupied galleries, information was obtained from which the prevalence of the insect could be gauged.

In each of three fields sixteen plots were laid out. The bushes in the three fields differed as regards their age from last pruning. The three sets of plots were treated alike, and each manure tested was tried in each field. Four plots in each field were left unmanured as controls.

Owing to the size of experimental errors the results obtained are not conclusive. The experiments indicate that the best results may be expected from simple nitrogenous manures, particularly sulphate of ammonia and nitrate of soda. Lime, too, may be beneficial.

The organic and phosphatic manures gave results no better than the unmanured plots. Potash, in the form of muriate of potash, gave a better result than that obtained from the best control plots, but where it was combined with nitrogen as nitrate of potash, this result was not maintained.

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May, 1922.

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